Lesson learned from testbeam data analysis

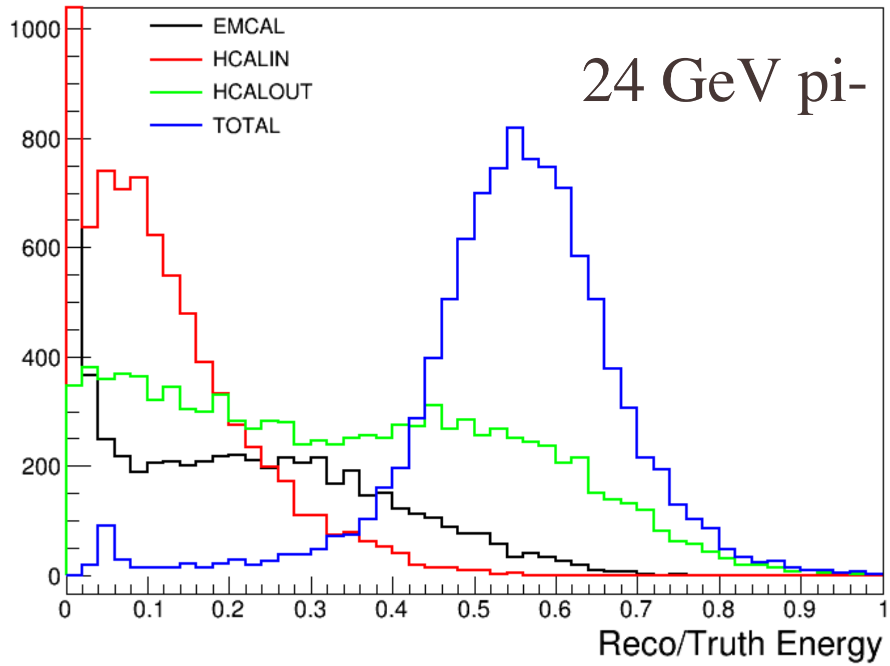
- Abhisek Sen

Lessons learned from testbeam

- How to build a hadronic calorimeter. 
- How to calibrate 
  - Cosmic
    - Tower by tower calibration, relative calibration between segments.
  - LED / Laser
- How to make a realistic simulation that describe data very well. 
- Data analysis: 
  - Energy reconstruction
  - Hadron and electron response
  - Tune for e/pi response

Calibration

Why calibration is so crucial?

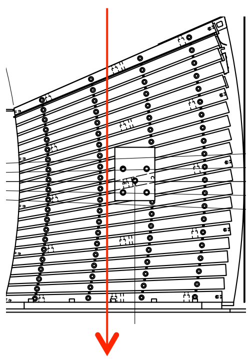


Need all three segments properly calibrated.

- Reconstructed energy from the simulated towers.
- Clear peak when you add all three calorimeters.
- Full calibration of all three calorimeters is particularly important in segmented calorimeters like ours to reconstruct full energy.

How to calibrate?

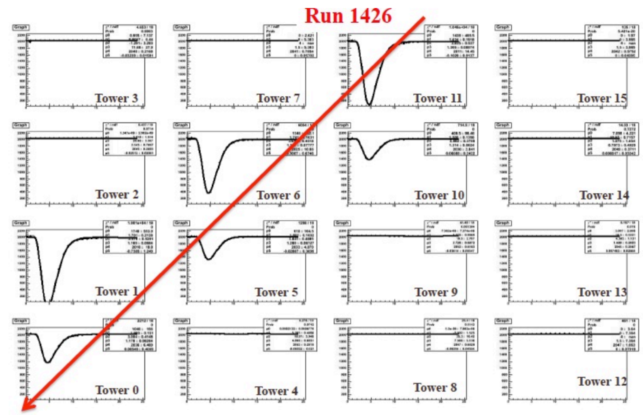
Vertical cosmics



8 runs to scan full inner and outer 4x4 towers. Primary calibration source for testbeam analysis.

Not a practical method for actual physics running.

Self-triggered cosmics



Trigger rate was 10x than cosmic rate.

Complication: Need to adjust threshold and minimum number of hits to define a trigger. Cosmic muon direction.

LED

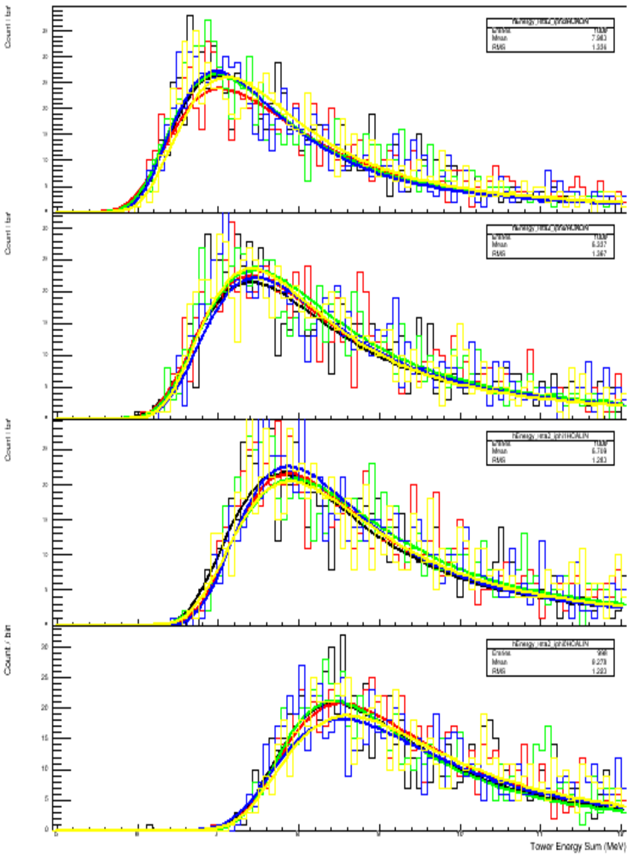
Very fast method. Good for temperature compensation.

Couldn't drive all LEDs with same voltage and current.

Replace the LED system.

HCALIN vertical cosmics

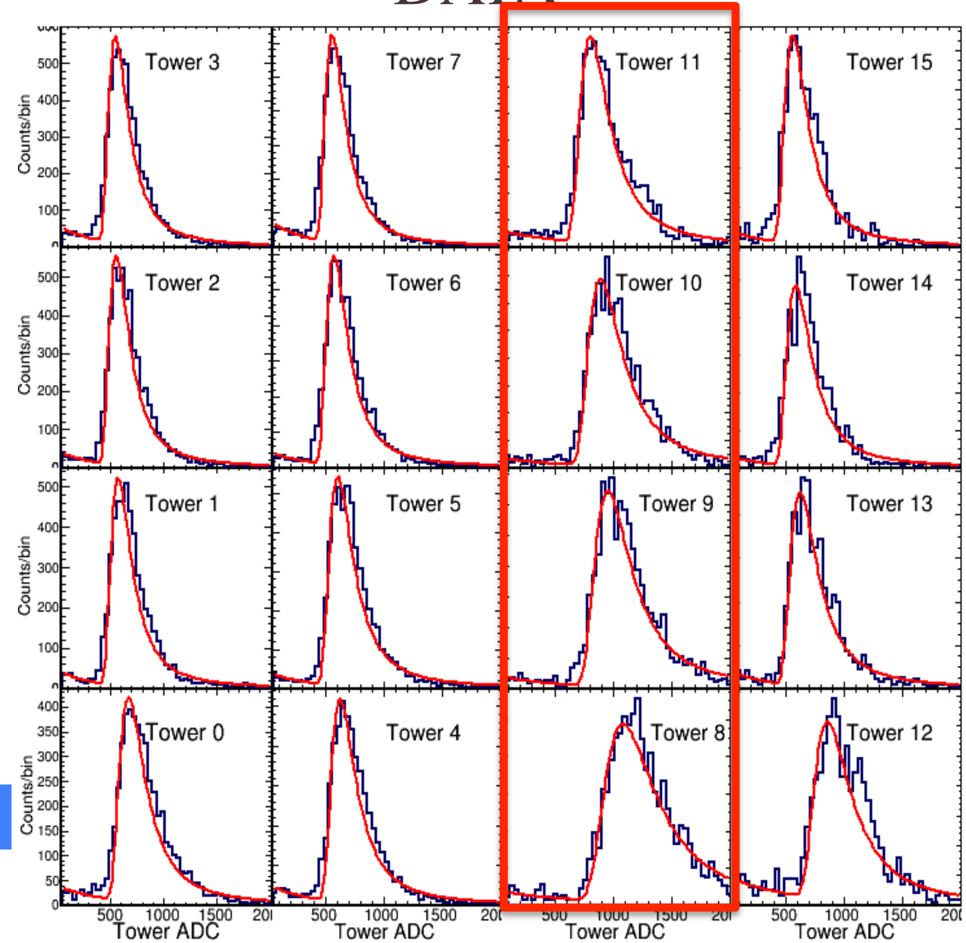
SIMULATION



Top tower

Bottom tower

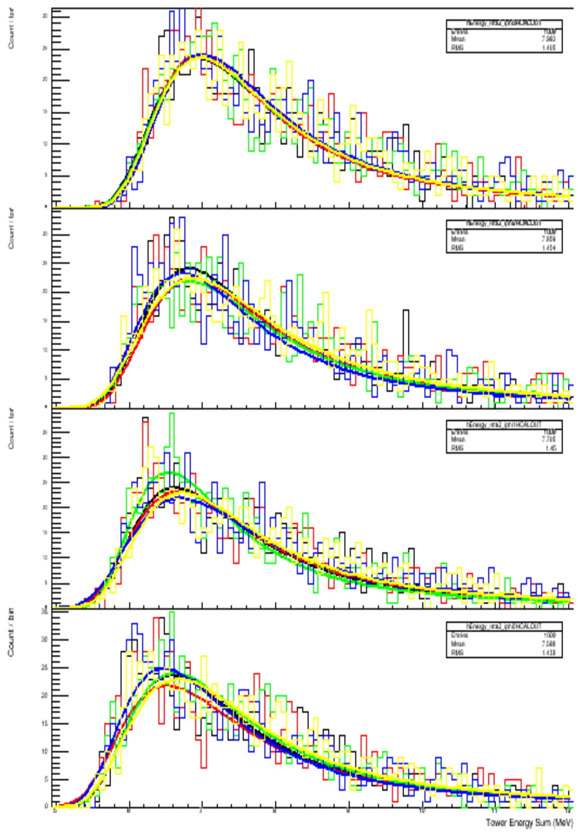
DATA



The tiles are tilted. The cosmic muon pathlength is higher for the bottom tiles.

HCALOUT vertical cosmics

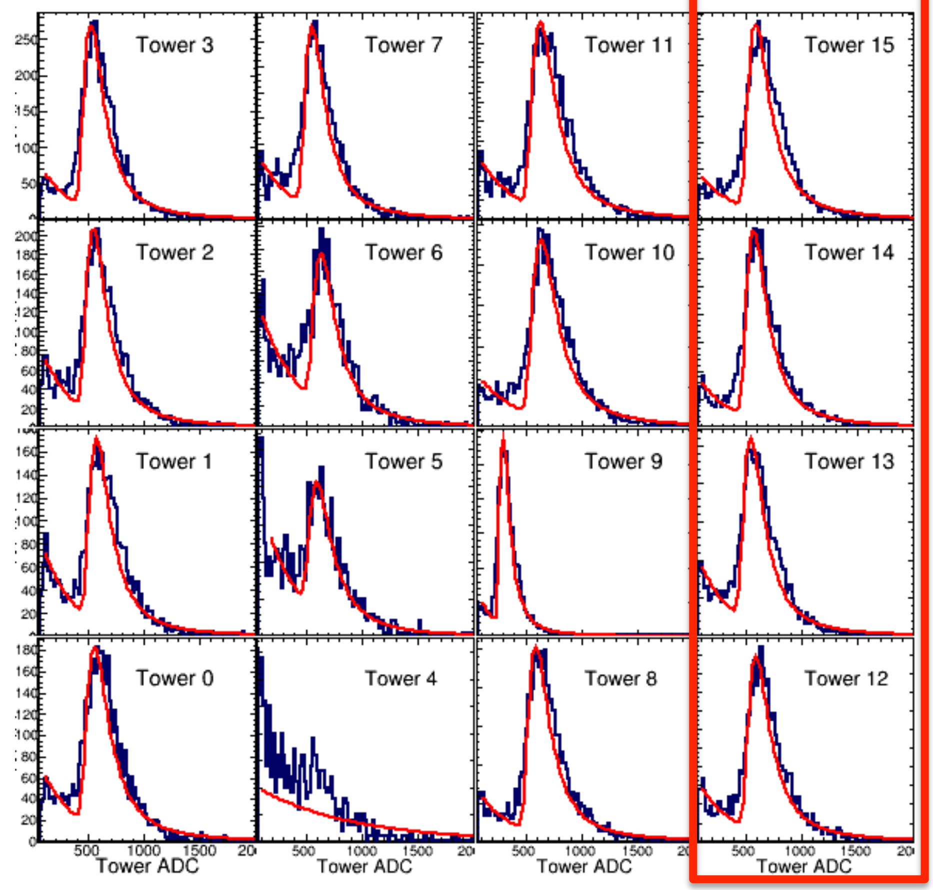
SIMULATION



Top tower

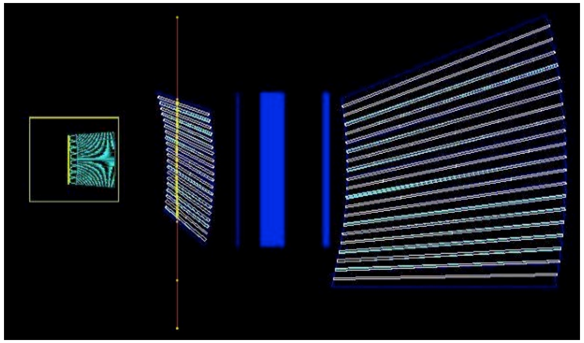
Bottom tower

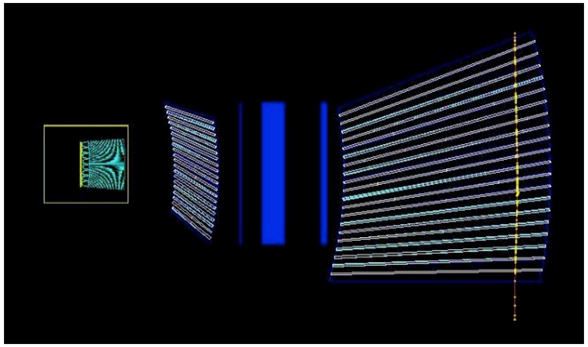
DATA

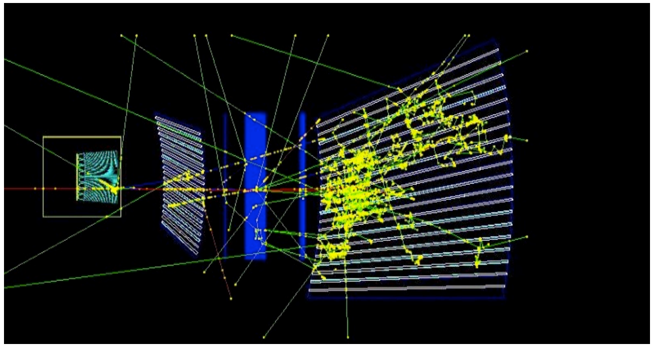


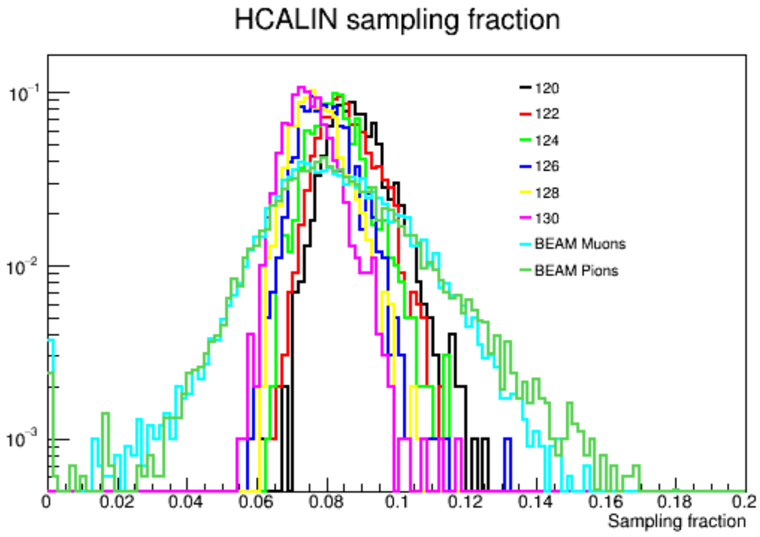
The outer HCAL tiles are tilted in the opposite way.

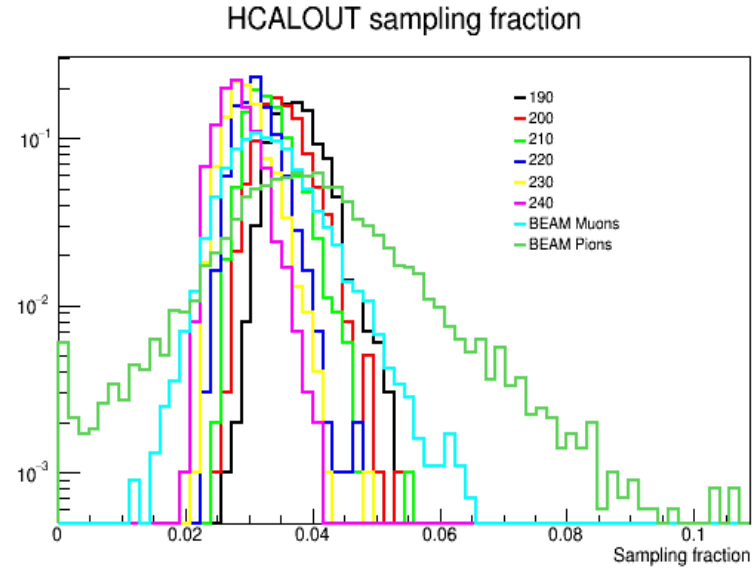
Does geometry matter?







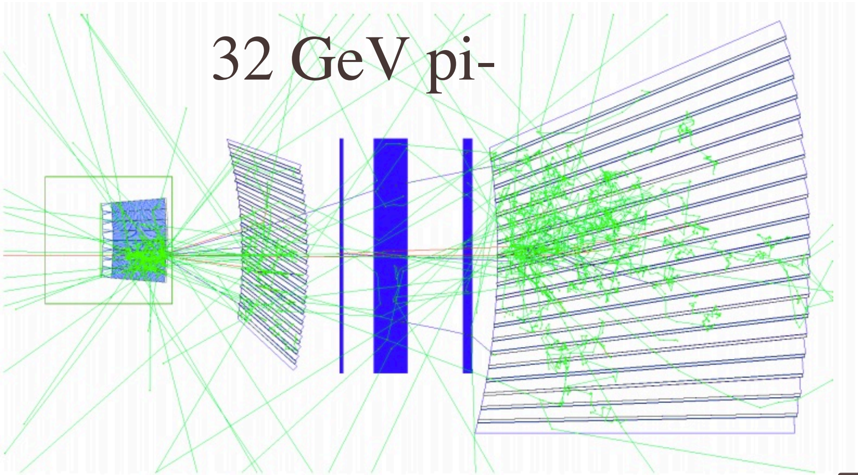




No significant change in sampling fractions.

Simulation

A realistic simulation



HCALIN Parameters:

1/5 pixel / HG ADC channel
32/5 pixel / LG ADC channel
0.4 MeV/ LG ADC
0.4/32 MeV/ HG ADC

HCALOUT Parameters:

1/5 pixel / HG ADC channel
16/5 pixel / LG ADC channel
0.2 MeV/ LG ADC
0.2/16 MeV/ HG ADC

Using standard sPHENIX software framework

Geant4 Hits
↓
Apply Birk's correction
↓
Tower sum of G4 hits within 0-60 ns
↓
Get pixel counts & ADC
↓
Add pedestal fluctuation
↓
Sampling fraction correction
↓
Calibrated simulation towers

Data analysis

HCAL - DATASET

- Standalone:
  - Only with inner and outer HCAL.
- Joint:
  - With EMCAL & HCAL
- Tilting:
  - Tilted +/- 5 degree (Joint)

3 available datasets

Hadron Selection: (common to all dataset)

Cherenkov cut: C2_inner+C2_outer < 20

No hit in the veto counter (ADC<15)

Valid Single hodoscope fired (V/H)

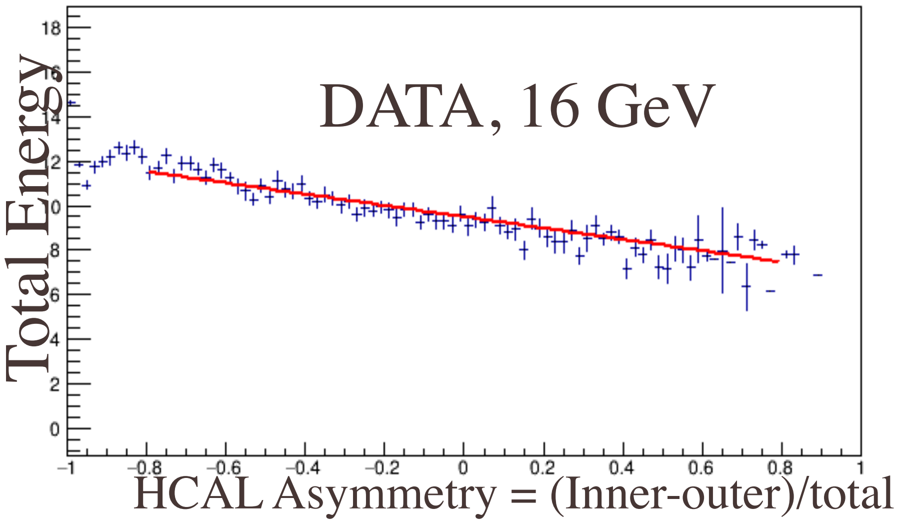
Code:

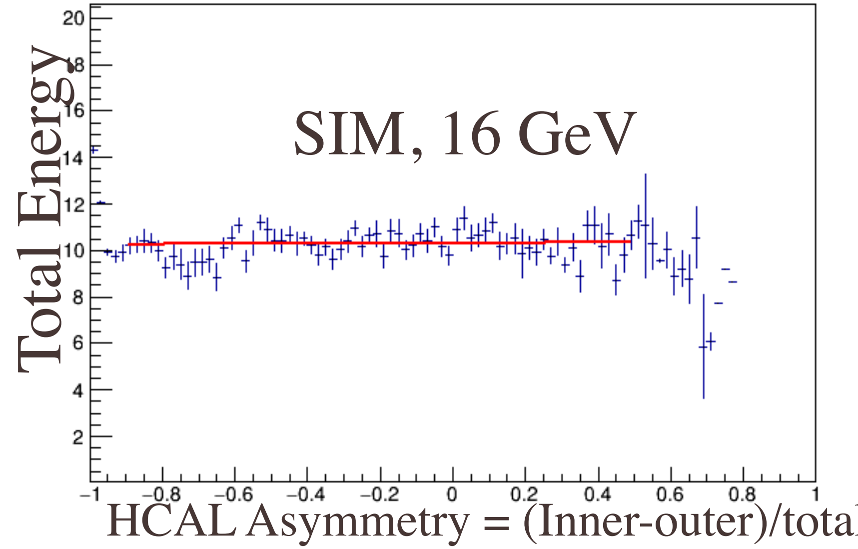
https://github.com/sPHENIX-Collaboration/analysis/tree/master/Prototype2/HCAL/ShowerCalib

Standalone HCAL data

Balancing calorimeters

Inner and outer are balanced?





- Inner and outer not balanced.
- A miscalibration on the overall scale between two segments.

- Cosmic calibration was tuned with HG channels but above data is LG.
  - Gain difference of 32 (inner) and 16 (outer) was taken care of.

Methods

Method 1: $E_{reco} = E_{inner} + p * E_{outer}$

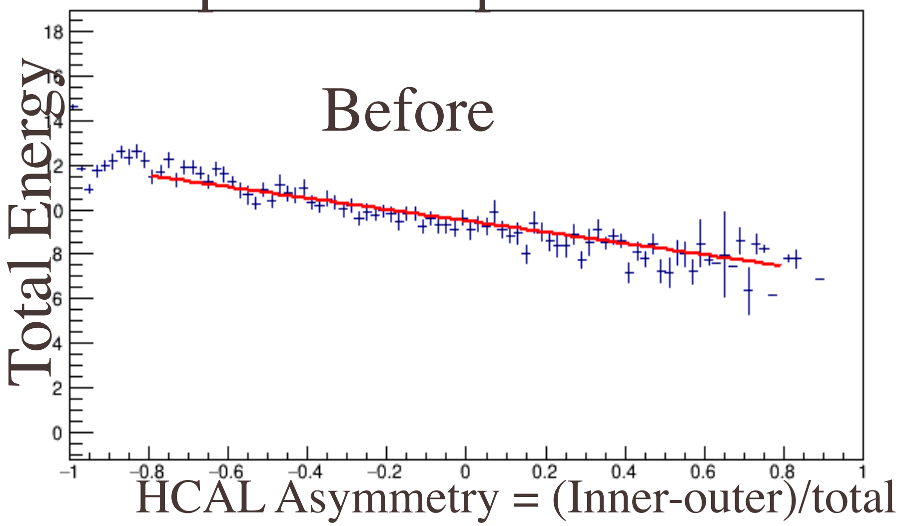
Use Minuit to minimize: $\sigma_{E_{reco}} / \langle E_{reco} \rangle$

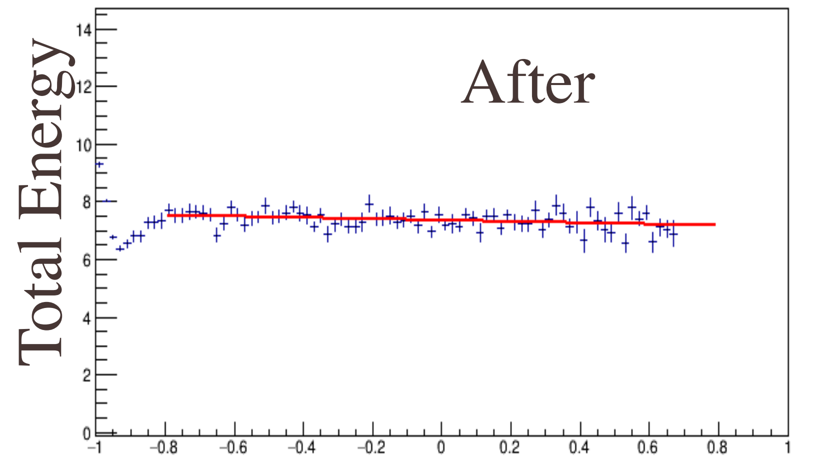
p ~ 0.5 which gave best possible resolution.

(Myy presentation from 26th July HCAL meeting + testbeam workfest)

Method 2: $E_{reco} = E_{inner} + p * E_{outer}$

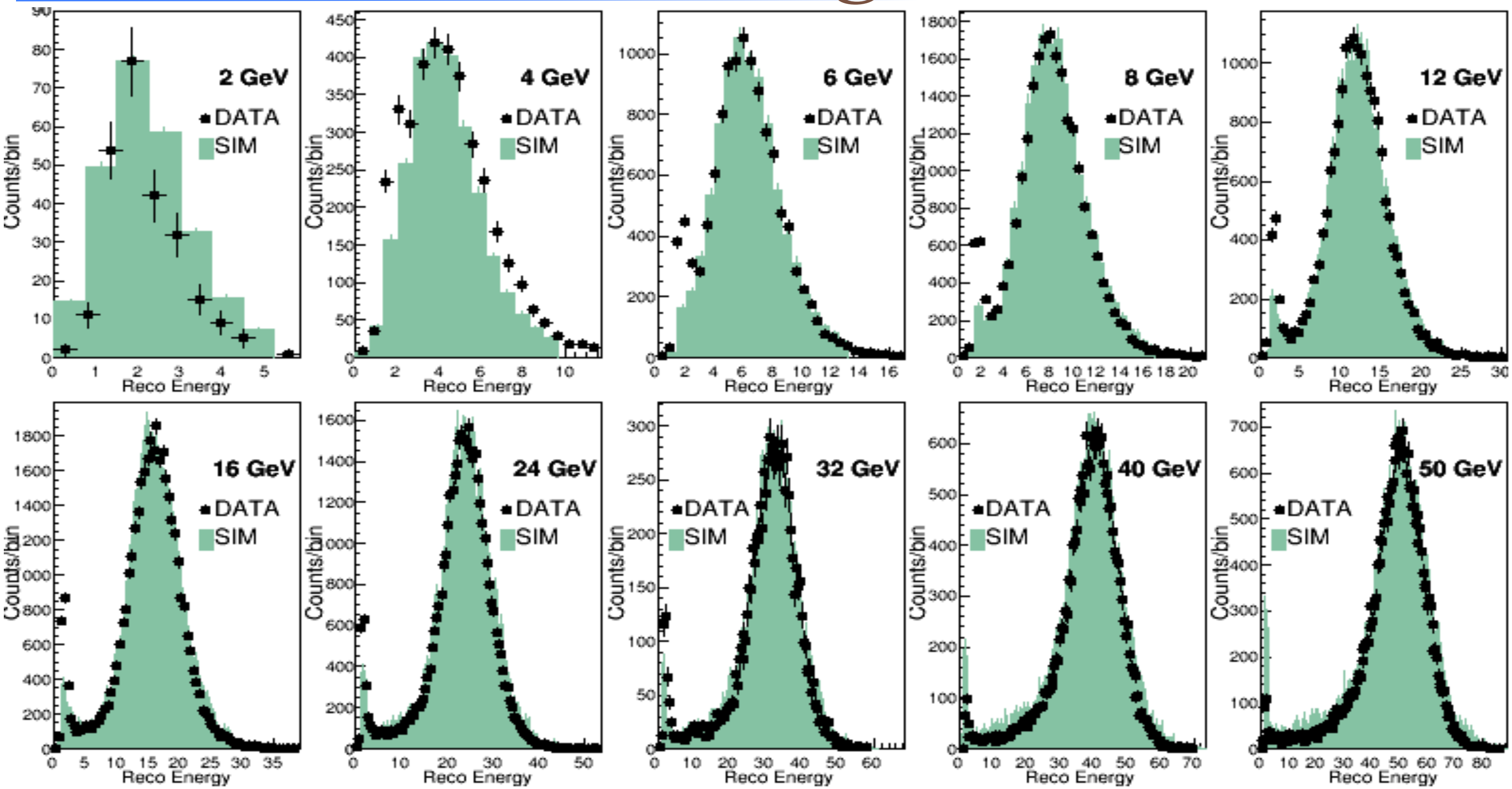
Find p when slope ~ 0





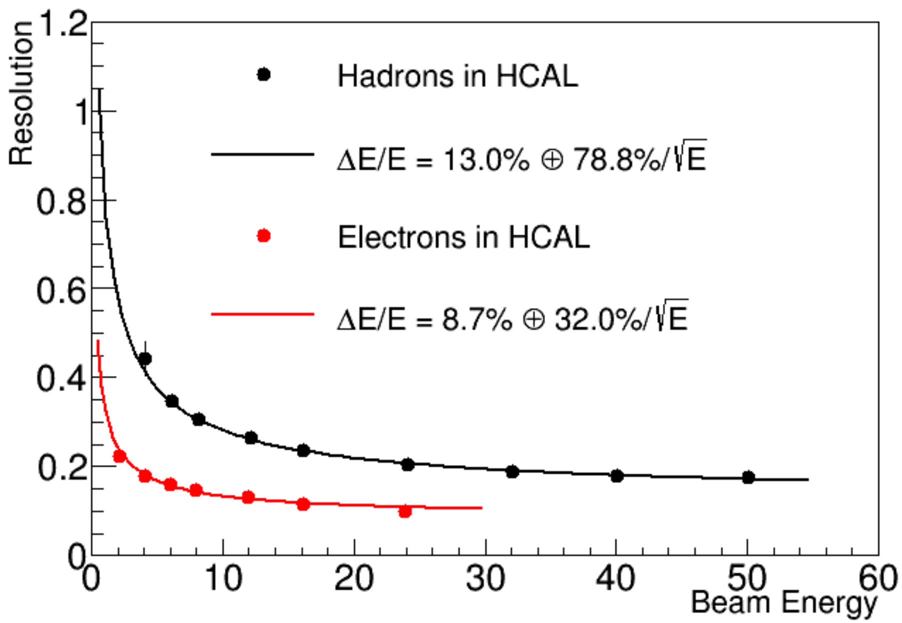
p ~ 0.5 averaged over all energies [8-28 GeV]

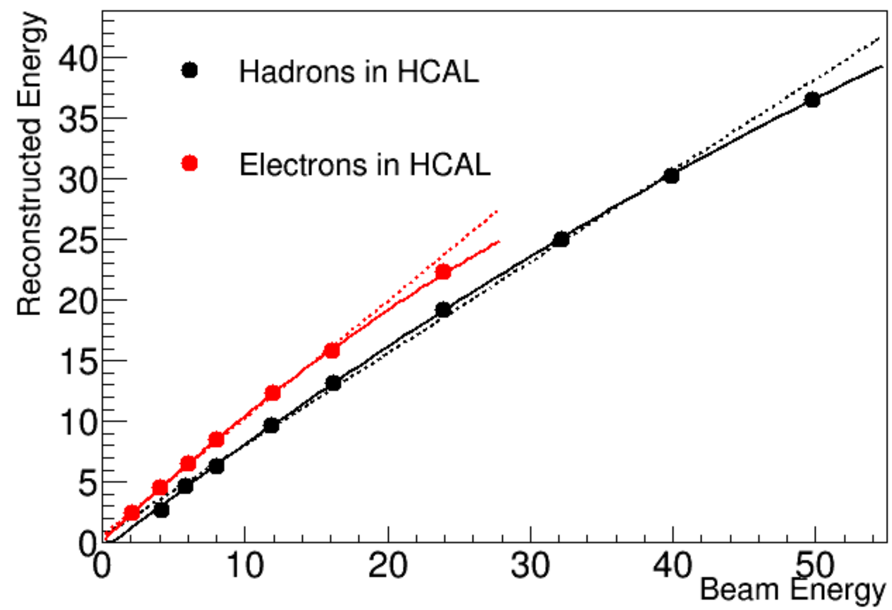
Hadron signals



- Best way to represent our measurements is to show full comparison at all the energies.
- The high tail in the low energies is due to higher hadron shower fluctuations.
- The low tail in the high energies is due to leakage at the back of the calorimeter.

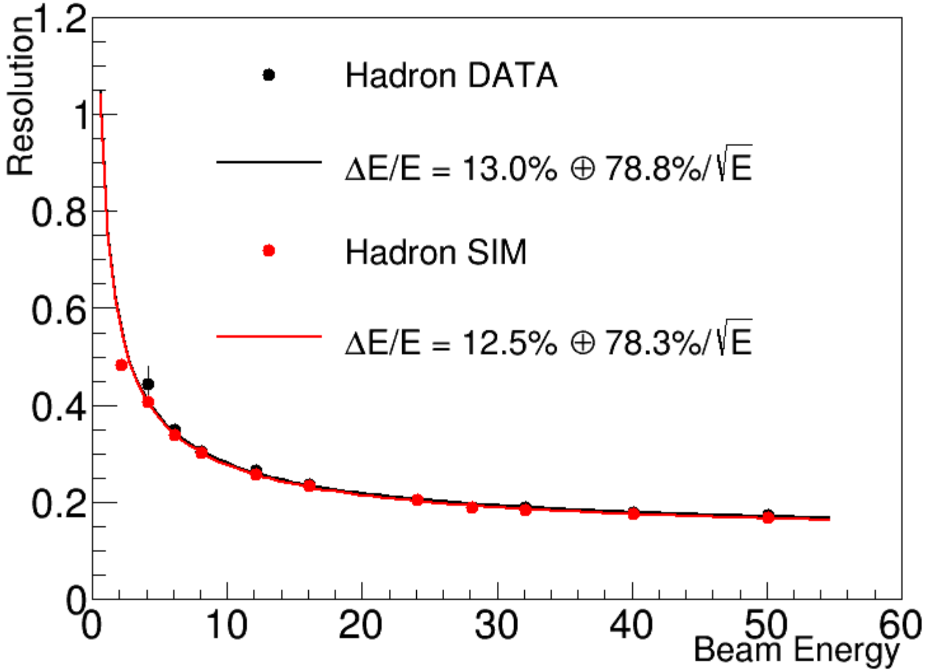
Resolution and Linearity

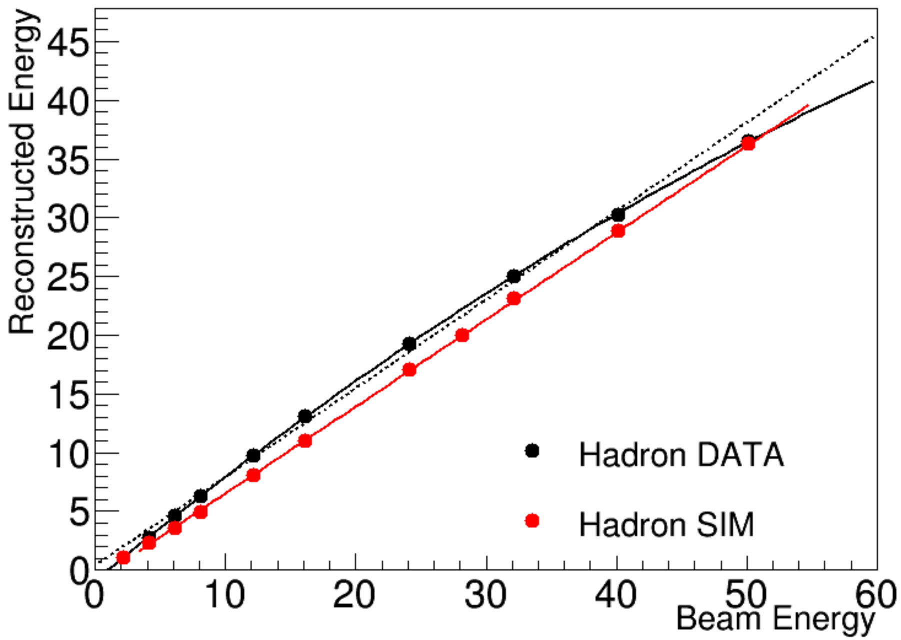




- Calibration:
  - Cosmic calibration for tower to tower variations.
  - A extra weight of 2 applied to the inner HCAL to balance two sections across all the energies.
- A small systematic error can be extracted on the resolution because tails [ignored till now].
- Low energy hadrons have significant beam momentum spread, no unfolded.
- Electron data was only available from 2-24 GeV because of the Cherenkov threshold.
- Response is not linear. A polynomial order 2 fits better than straight line.

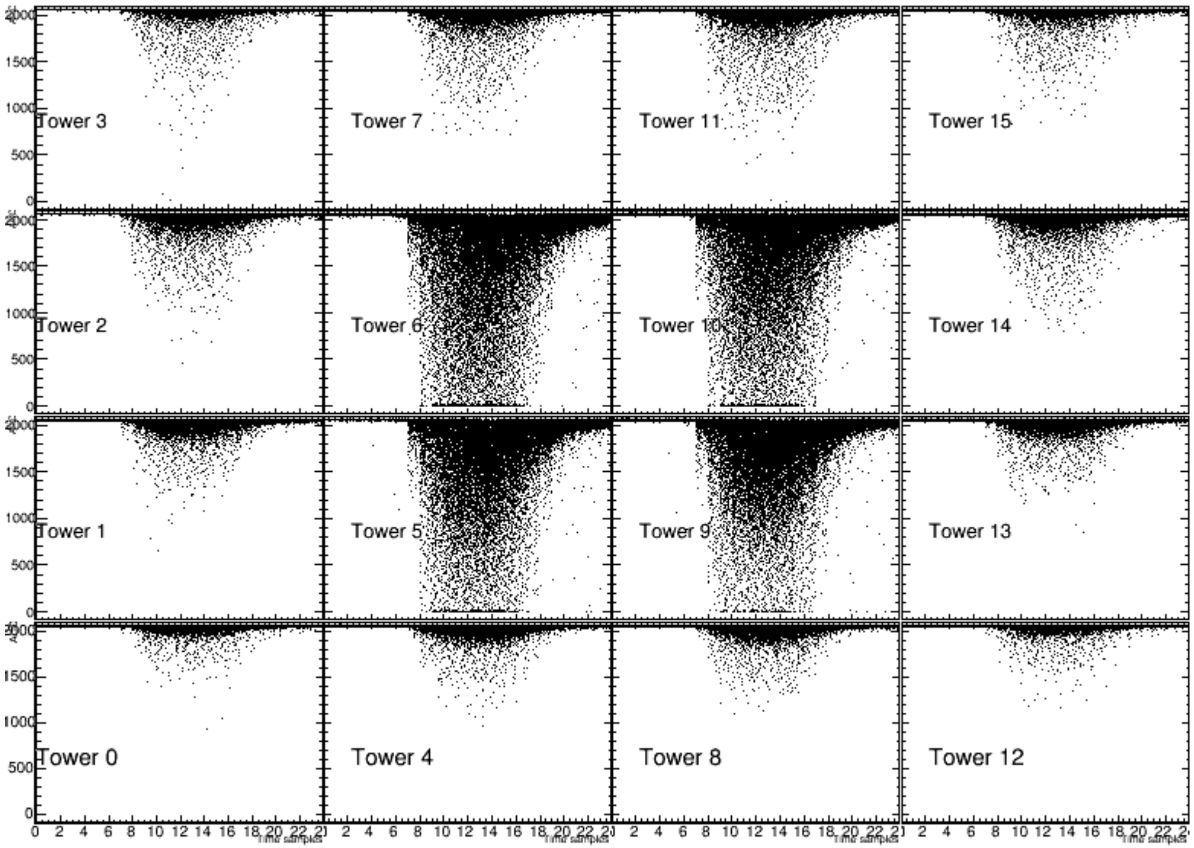
Comparison with simulation





- Excellent agreement between data and simulation.
- Simulation is linear while data is not.

What creates the non-linearity?



Outer HCAL
4x4 towers
Low Gain

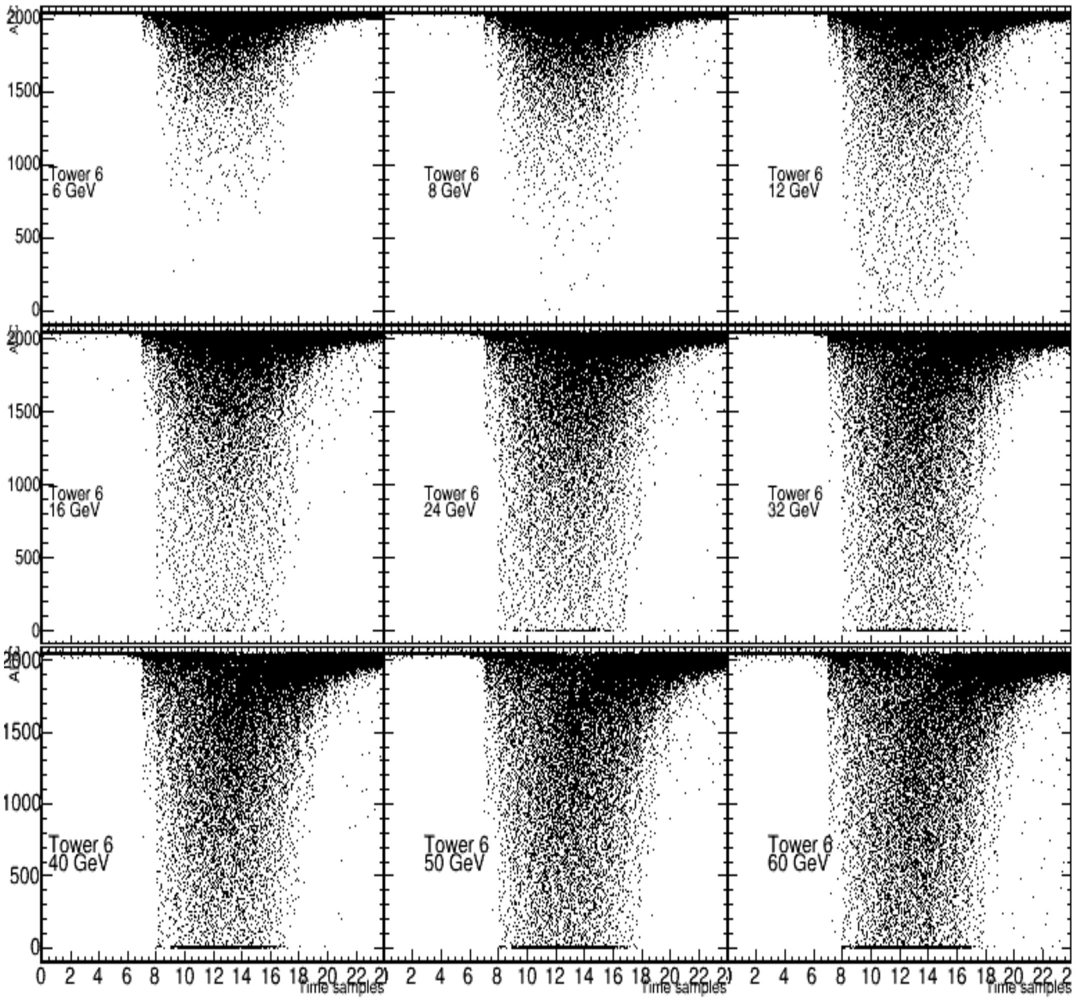
Hadron signals at
E = 40 GeV.

X axis: time samples
Y axis: ADC

12 bit ADC
Dynamic range 2048-0
(negative polarity)

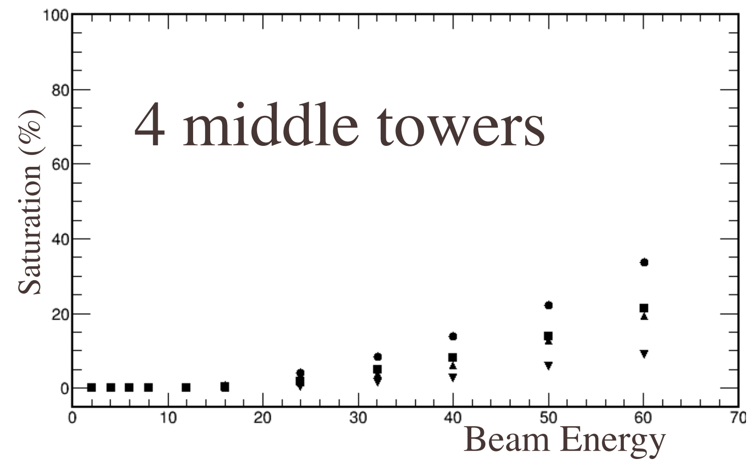
Significant saturation can be seen in 4 middle towers.

Saturation fraction



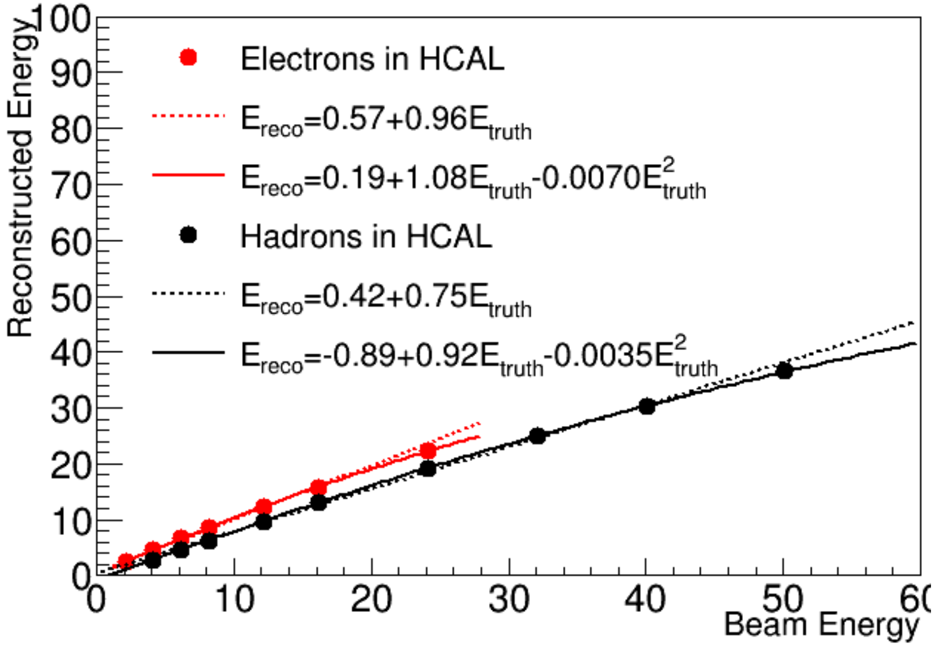
Signal selection criteria:

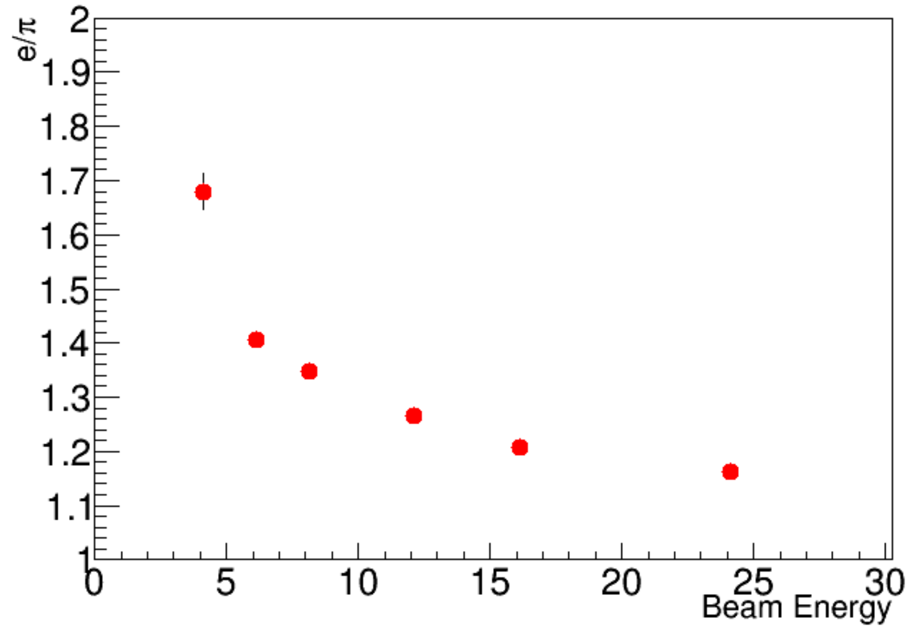
- Hadron Cherenkov cut.
- SumE>2 GeV



The non-linearity observed is a saturation effect.

HCAL e/pi

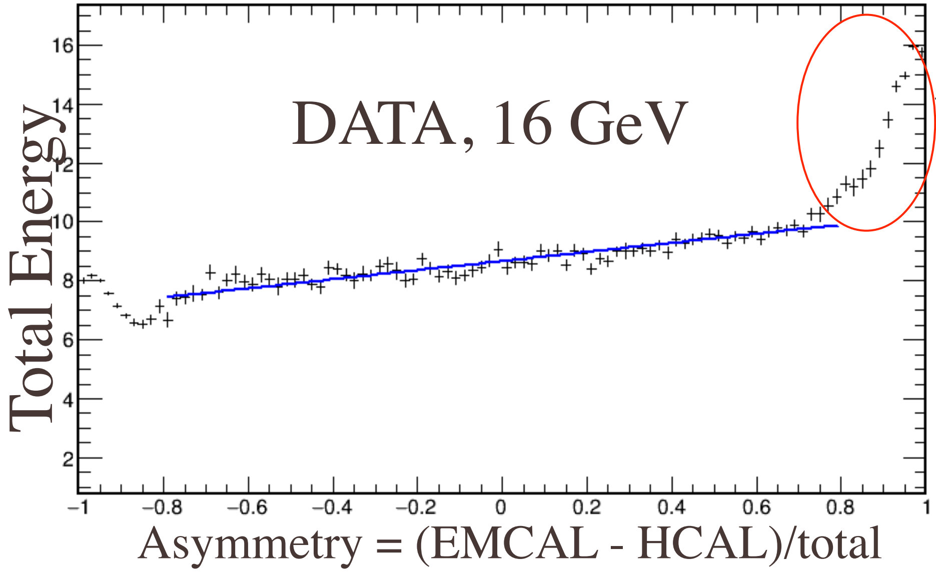




- HCAL e/pi would not be possible to measure if EMCAL is in front.
- Useful for HCAL assisting EMCAL with electrons leaking at the back of EMCAL.

sPHENIX configuration (EMCAL+HCAL)

Balancing EMCAL



Electrons with no Cherenkov

HCAL: Tower-to-tower calibration is from cosmic MIP events.

EMCAL: Tower-to-tower calibration is from 120 GeV MIP events.

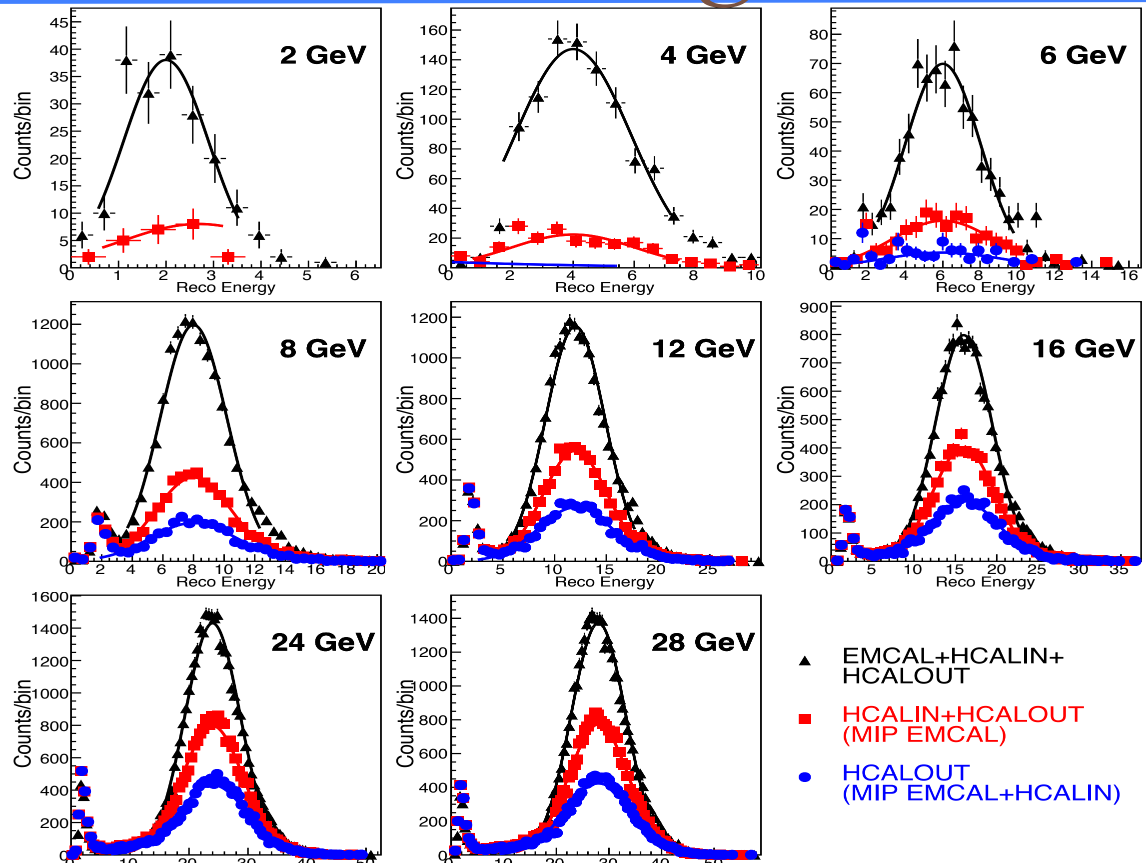
Expected:

EMCAL was calibrated for electrons.

HCAL was calibrated hadrons.

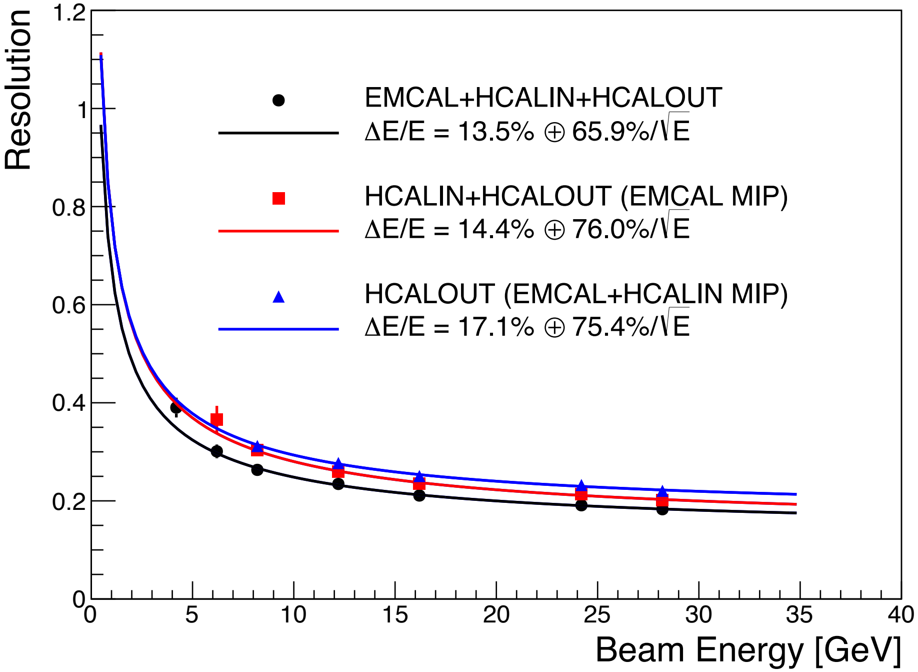
EMCAL's hadron response will be lower due to e/h response.

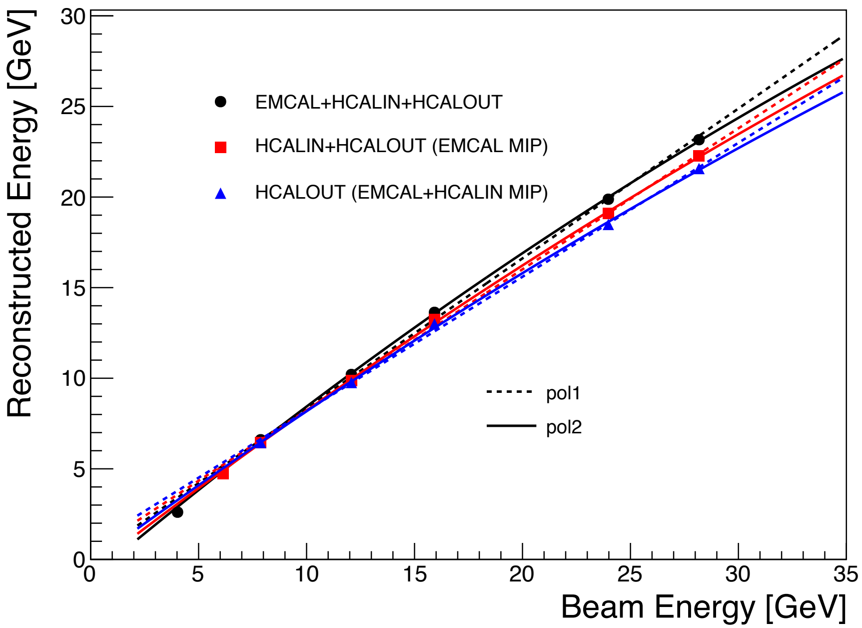
Event categorization



- Event categorization to reduce longitudinal fluctuations
  - **HCALOUT** (MIPs through EMCAL and Inner HCAL)
    - Shower started in outer/MIPs all calorimeters.
  - **HCAL** (MIPs through EMCAL)
    - Shower started either in inner/outer/MIPs all calorimeters.
  - **FULL**
    - All showers irrespective of their start position

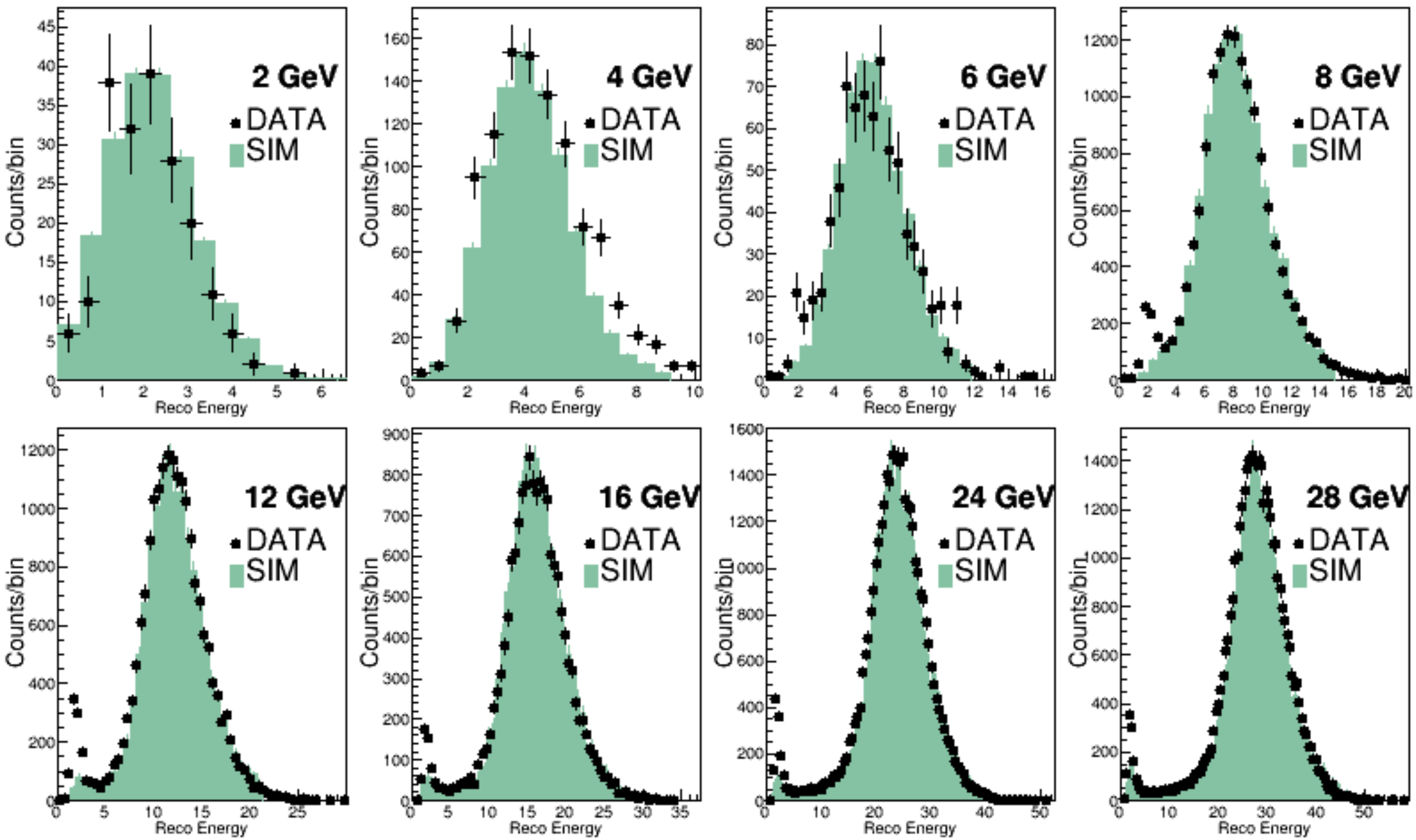
Resolution and linearity





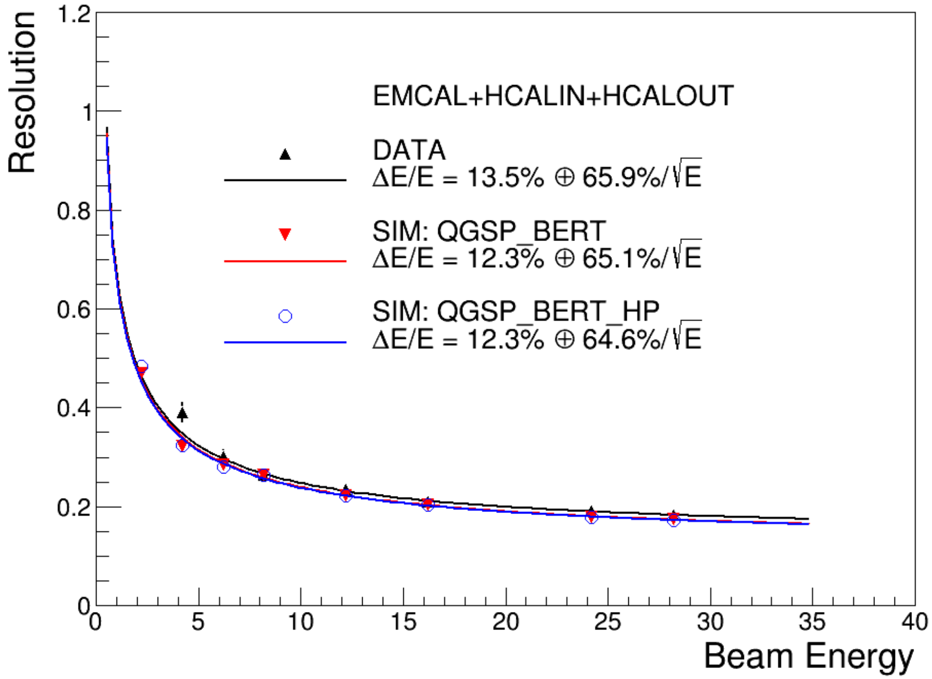
- EMCAL was also balanced with HCAL. Weight applied ~0.8, no energy dependence seen.
  - Due to “h/e” since EMCAL calibration was done for electrons.
- Asymmetry cut:(EMCAL-HCAL)/sum<0.8 cut applied to remove electron contaminations
- Better energy resolution observed with all three segments.

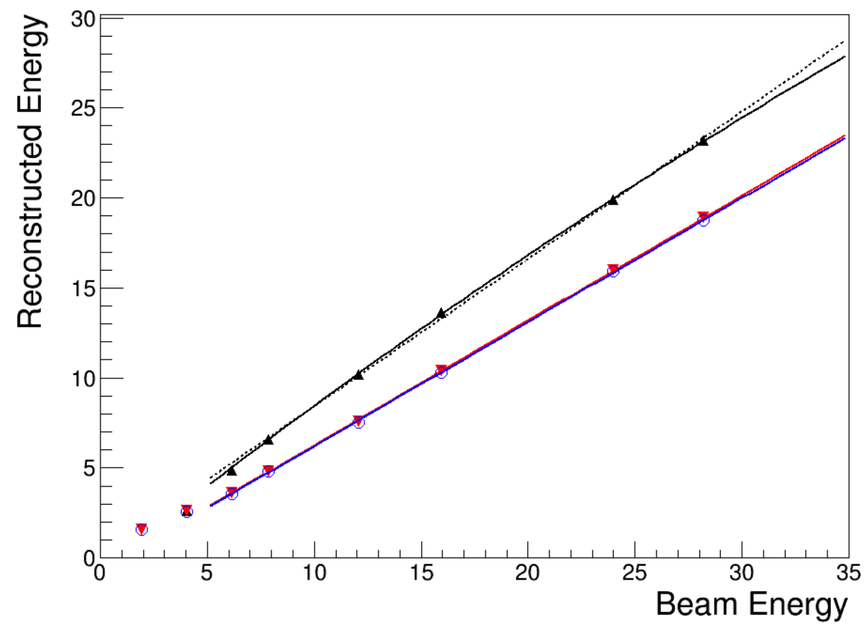
Comparison with simulation



- Comparison of FULL events between data and simulations.
- Good agreement at all energies with simulation.

Comparison with simulation





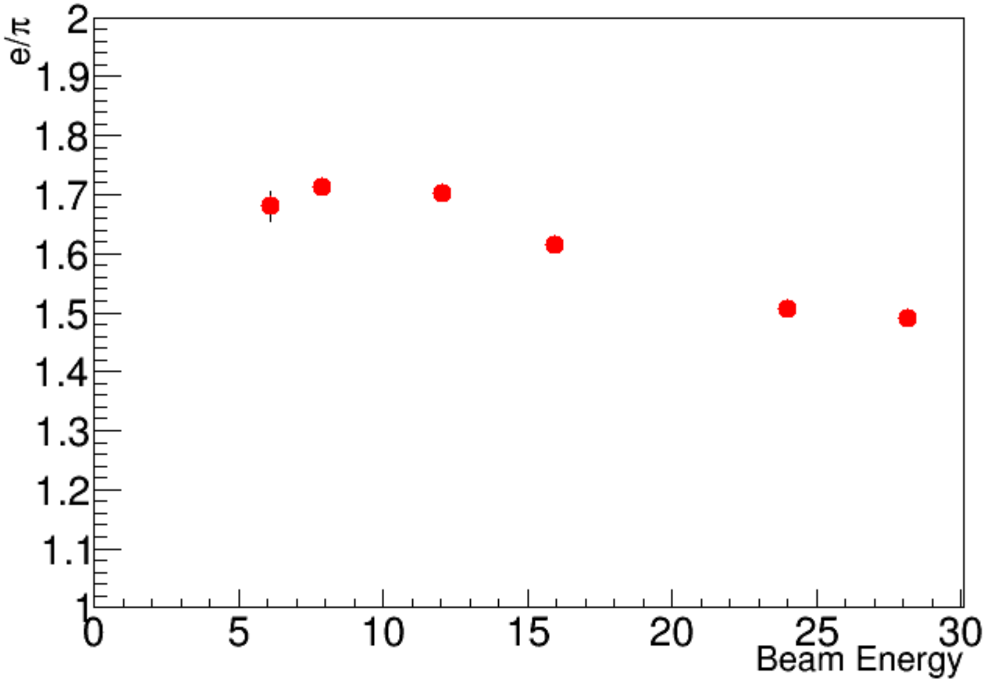
- Excellent agreement between simulation and data.
  - Two physics lists: QGSP_BERT (default) and QGSP_BERT_HP
- Linearity is quite different in simulation.

sPHENIX configuration e/pi

Hadrons: $$E_\pi = E_{EMCAL} + E_{HCAL}$$

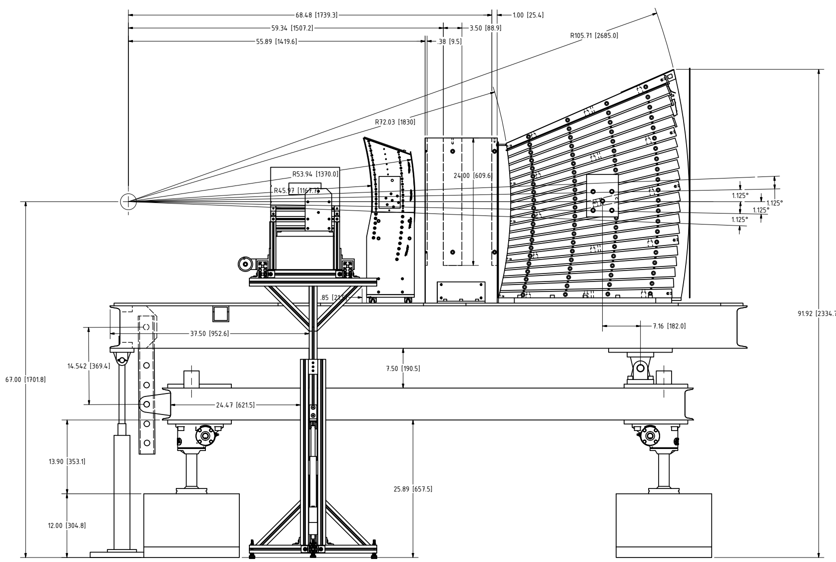
Electrons: $$E_e \approx E_{EMCAL}$$

$$\frac{E_{EMCAL} - E_{HCAL}}{E_{EMCAL} + E_{HCAL}} > 0.8$$



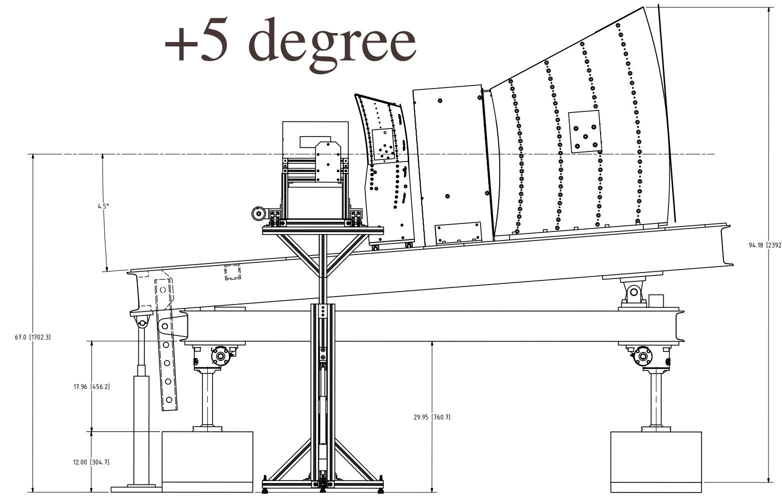
Tilting

Normal position



HORIZONTAL POSITION

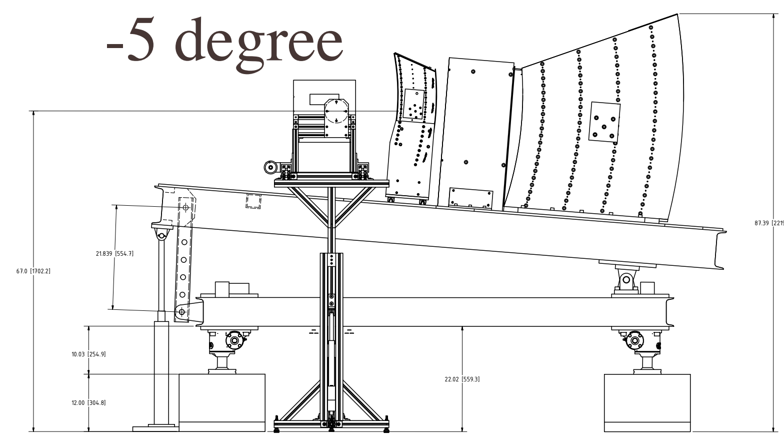
+5 degree



+4.5° POSITION

PRELIMINARY

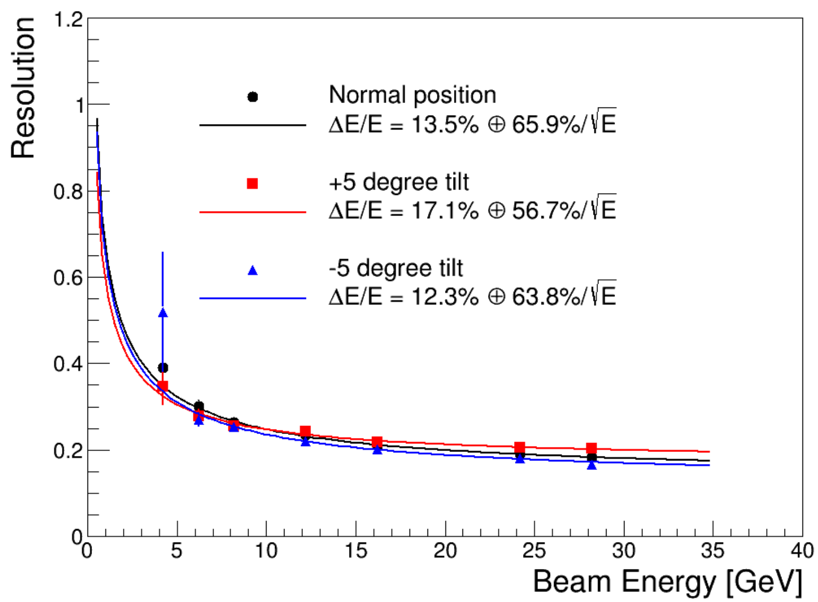
-5 degree

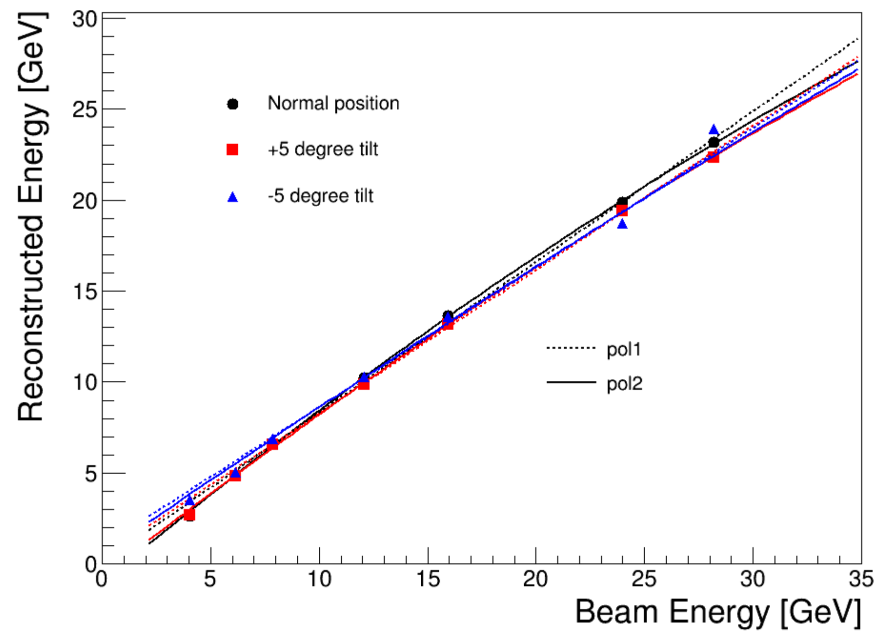


-4.5° POSITION

PRELIMINARY

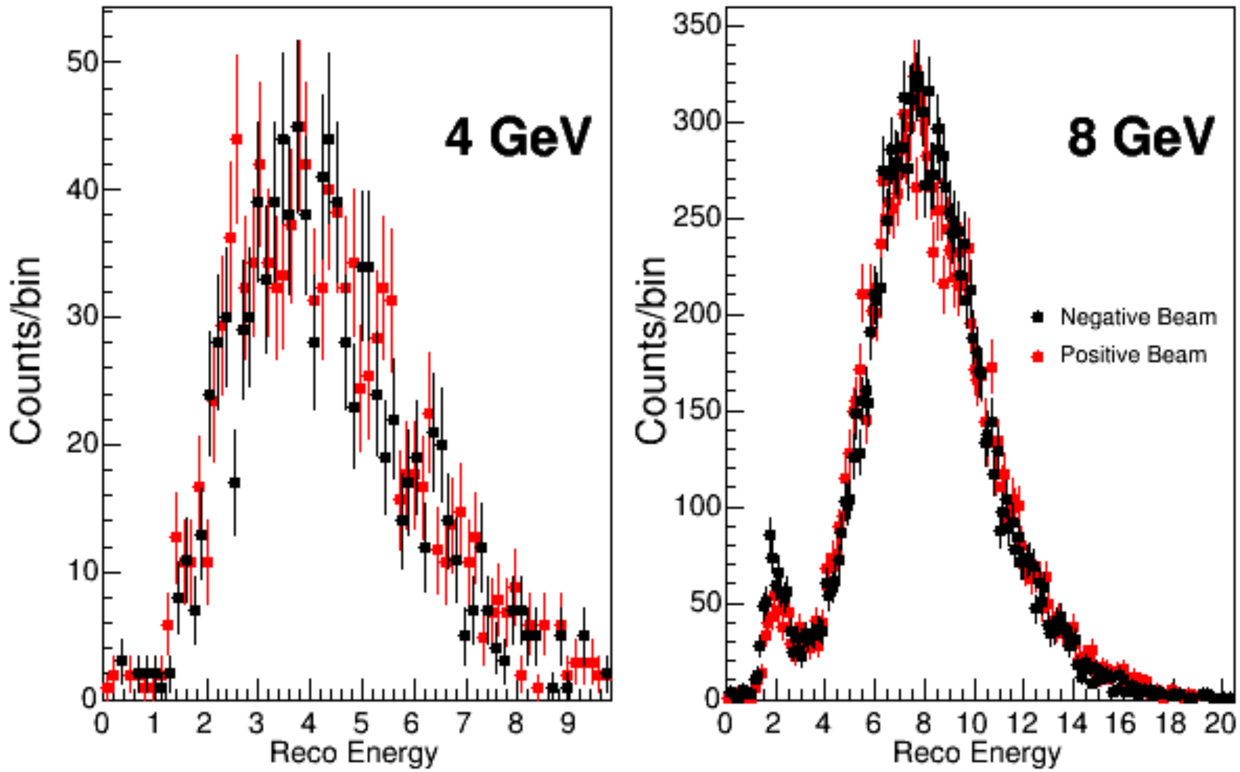
Resolution and linearity





- Similar resolution observed with all three configurations.
- NOT included in the paper.

Positive and negative beam



- Most of energies collected are with negative beams.
- I only could found +4 GeV and +8 GeV that was also taken.
- Will pi+ and pi- have separate response?
  - Not likely.

Summary

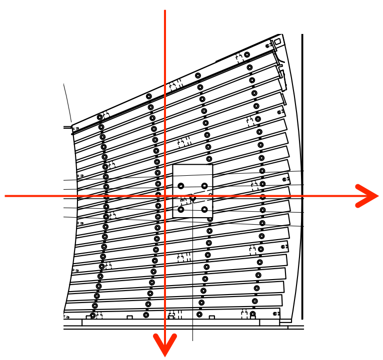
- Testbeam was fun.
- We learned a lot about hadronic calorimeter.
- Resolution observed meets sPHENIX specification.
- Excellent agreement observed between data and Geant4.
- HCAL nonlinearity observed due to SIPM saturation.
- Need more investigation on calibration with self-trigger and LED system.

BACKUPs

HCAL Tower-by-tower calibrations

- Collected cosmic data at highbay.
- Compared with cosmic simulations from Murad for a tower-by-tower calibration.
- We intended LEDs for another confirmation on the calibration but couldn't drive with all LEDs with same voltage and currents.

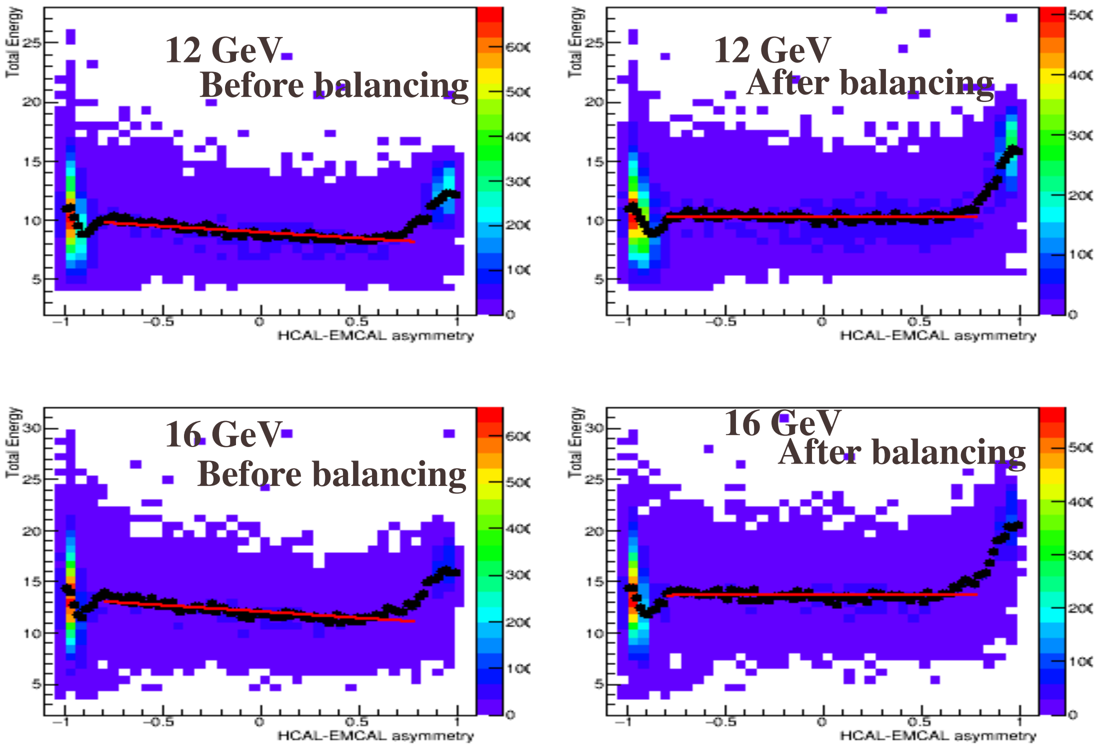
HCAL calibration done with cosmic μ's
Edep ~ 750 Mev/1 GeV (Inner/Outer).

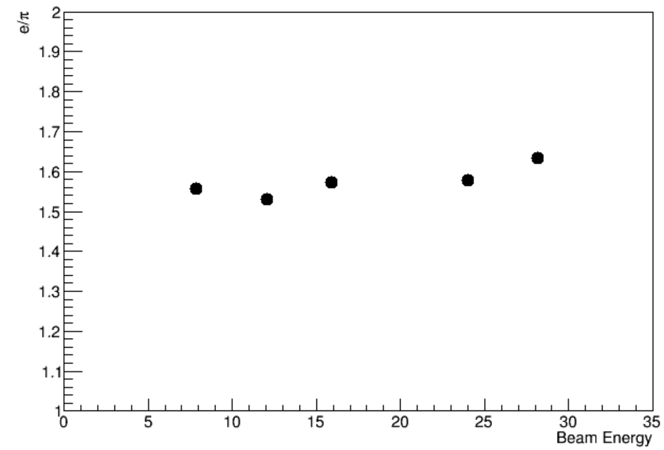


Does the geometry matter?

Example of Outer HCAL calibration with cosmic muons

EMCAL e/pi





Done by balancing EMCAL with respect to HCAL.
No energy dependence seen in beam energy 8-28 GeV.
The low energy HCAL data is not reliable but from my analysis there is a hint that it is higher at lower energies.
e/pi ~ 1.55 between 8-28 GeV.